

The University of Chicago

ANATOMY OF THE TRANSITION
REGION IN GOSSYPIUM

A PART OF A DISSERTATION SUBMITTED
TO THE FACULTY OF THE DIVISION OF THE
BIOLOGICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF BOTANY

1931

By
ALDA MAY SPIETH

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ANATOMY OF THE TRANSITION REGION IN GOSSYPIUM

CONTRIBUTIONS FROM THE HULL BOTANICAL LABORATORY 449

ALDA MAY SPIETH

(WITH TEN FIGURES)

Introduction

The genus *Gossypium* has been the subject of much investigation from the physiological and anatomical viewpoints. Although much work has been done on the development of the flower and lint fiber, many anatomical details of the vegetative structures require further investigation. This paper describes the root-stem transition region.

Seeds of *Gossypium hirsutum* L. were used in this study, of the upland variety Dixie Triumph. The varieties Acala, Cleveland 54, and Delfos were studied for comparison. The seeds, which were treated with sulphuric acid to limit the development of cotton wilt, germinated rapidly under greenhouse conditions. By the end of the fourth day the hypocotyl may attain a length of 10-12 cm., with a primary root of equal length or longer. In seedlings five days old the cotyledons are fully expanded and the primary tissues are mature in the root and lower part of the hypocotyl. Less mature and older seedlings were used to determine the progressive development and maturation of the tissues.

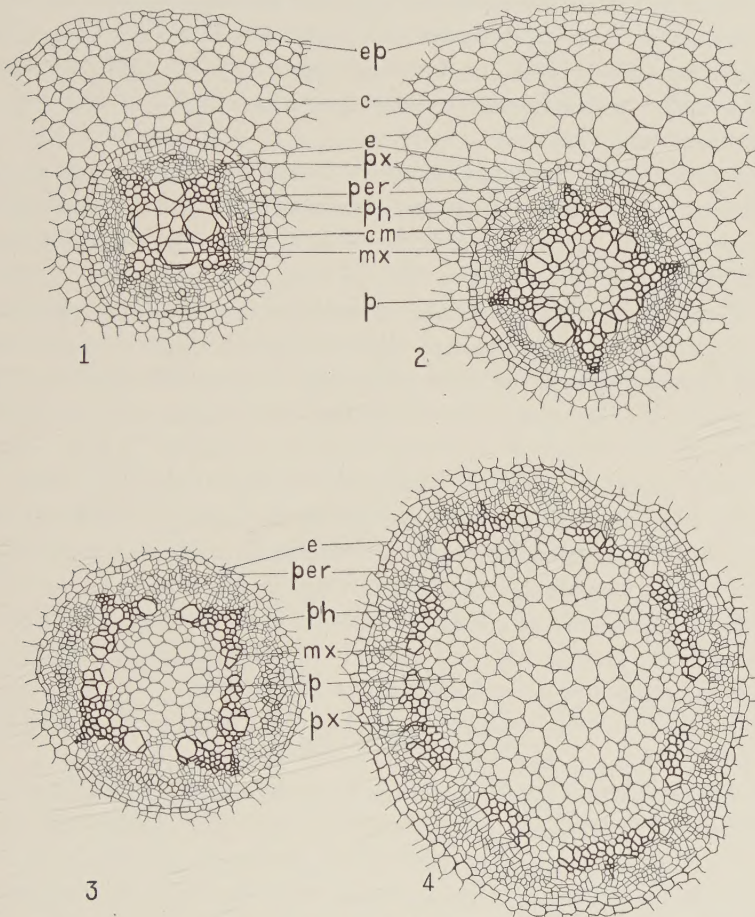
The transition region involves the greater part of the hypocotyl. The xylem is completely endarch approximately 1-2 cm. below the divergence of the cotyledons.

Investigation

PRIMARY ROOT

The primary root of the cotton plant is generally a tetrarch, exarch protostele (fig. 1). The protoxylem is composed of elongated spiral and annular elements, which usually are stretched to such an extent that the thin walls of the annular elements collapse and the spiral bands appear straightened out. The metaxylem adjacent to

the protoxylem consists of scalariform and scalariform-reticulate tracheids; that in the center of the cylinder consists of four or eight large tracheae, which may or may not be separated by cells with



FIGS. 1-4.—Fig. 1, transverse section of primary root: *cm*, cambium; *c*, cortex; *e*, endodermis; *ep*, epidermis; *mx*, metaxylem; *per*, pericycle; *ph*, phloem; *px*, protoxylem. Fig. 2, lower transition region showing pith. Fig. 3, metaxylem separated by parenchyma. Fig. 4, four transition bundles with alternating tangential metaxylem.

scalariform thickenings. The latter elements do not mature until secondary thickening begins.

Alternating with the protoxylem points are four groups of phloem.

These groups are separated from the central metaxylem by parenchymatous cells. The protophloem is parenchymatous and is soon crushed. The metaphloem consists of sieve tubes, companion cells, and parenchyma. When the primary root matures, the walls of some of the phloem cells external to the cambial initials thicken. Thus thickened phloem cells are formed adjacent to the cambial initials. Sieve tubes and companion cells occur at each end of this row of thickened elements.

The pericycle consists of a single layer of cells, external to the phloem region, and of two or three layers of cells over the protoxylem elements. The pericyclic cells are several times the length of their radial diameters.

The endodermis is composed of one layer of cells. The cells abutting on the phloem groups are filled with a mucilaginous substance, but over the protoxylem points this material is usually lacking. The endodermal cells are approximately the same length as the pericyclic cells.

The cortex includes the endodermis and 8-12 concentric layers of parenchymatous cells. These are usually isodiametric, although the two or three rows adjacent to the epidermis may be vertically elongated. The epidermis is a single layer of small cells.

Lateral roots originate early in the development of the primary root. These may be initiated in the pericycle abutting on the protoxylem long before the primary xylem matures.

ROOT-STEM TRANSITION

The first indication of a change from the exarch condition of the root to the endarch condition of the stem occurs approximately 1 cm. below the soil level. The hypocotyls that were studied were five days old and were 11-13 cm. in length from the soil level to the point of divergence of the cotyledons. At this age the primary tissues of the lower portion of the hypocotyl are completely differentiated, the cambium layer is active, and secondary thickening is initiated. In the upper portion of the hypocotyl, the primary tissues are beginning to mature. The more meristematic nature of the upper part of the hypocotyl is indicated by the continued elongation of this region and the lack of cambial initials.

At the cotyledonary node there is little differentiation of tissue, indicating that the older part of the axis is the lower portion of the hypocotyl and that the upper portion is much younger.

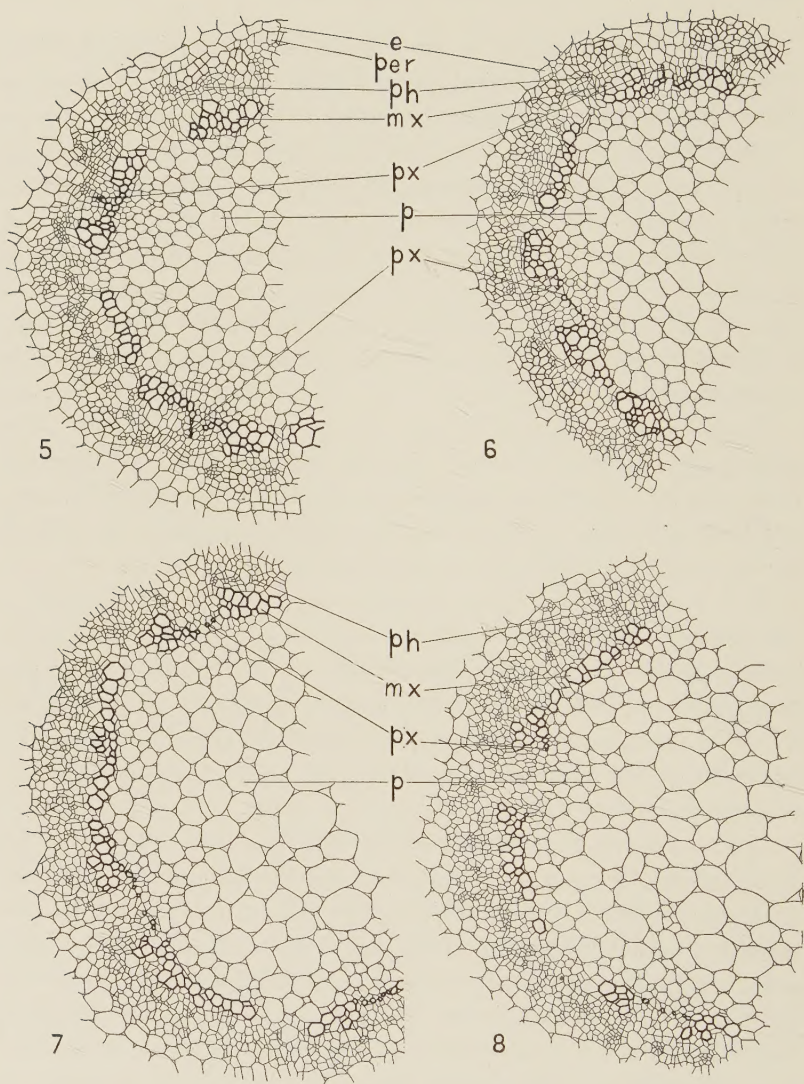
The first change in the root-stem transition takes place where the metaxylem differentiates in a ring, surrounding a pith of parenchymatous cells (fig. 2). The parenchymatous cells of the pith are circular in cross section, with intercellular spaces, and are elongated vertically. The phloem groups are larger, and one or two rows of the cells inside of the pericycle have thickened walls. Sieve tubes and companion cells differentiate at each end of the group, adjacent to the protoxylem points.

Within a short vertical distance the entire stele is enlarged. Four triangular shaped masses of protoxylem and metaxylem cells are laid down (fig. 3). Each triangle consists of the protoxylem at the apex and two tangential arms of metaxylem, which lie opposite the phloem groups and adjacent to the cambial initials.

At a slightly higher level, parenchyma is differentiated between the cells of the metaxylem arms. Four distinct triangular shaped groups of protoxylem-metaxylem elements are formed, with large tracheae at the two inner points of each triangle and with the protoxylem at the apex. Metaxylem continues to differentiate tangentially, so that there are bands of metaxylem alternating with the four transition bundles (fig. 4).

Continuing up the axis, the entire stele becomes larger. The endodermis and the pericycle persist as unbroken bands of cells. The protoxylem points differentiate in the same position, but the triangular shaped masses of metaxylem adjoining each protoxylem point differentiate laterally, so that each row lies at right angles to the protoxylem elements (fig. 5). These four bundles are typical transition bundles. The four large phloem groups are unchanged, except that three or four layers of the cells internal to the pericycle have thickened walls, although the protoplasmic contents are still dense. Small groups of sieve tubes and companion cells may be found at intervals among the thick walled elements.

The next change occurs approximately 2 cm. above the soil level. At this level each of the four original transition bundles consists of two rows of spiral elements separated by parenchyma and two lateral



FIGS. 5-8.—Fig. 5, transverse section of lower hypocotyl showing two transition bundles. Only one bundle shows parenchyma between the protoxylem points. Fig. 6, two transition bundles. In one bundle the protoxylem points are at right angles to metaxylem and are separated by parenchyma; in the second bundle the protoxylem points are in line with the metaxylem elements. Fig. 7, same transition bundles at slightly higher level. Fig. 8, upper transition, showing wide ray between one pair of bundles in contrast to narrow ray of second pair of bundles.

or tangential arms of metaxylem. This condition is first reached in the two opposite bundles. Each of these bundles now consists of two units with the protoxylem in essentially the same position and the metaxylem arranged tangentially. Alternating with these bundles are the other two transition bundles, in which there is as yet no parenchyma between the protoxylem points (fig. 5).

Secondary thickening takes place at this level and the cambium lays down secondary xylem adjacent to the tangential rows of metaxylem. Secondary phloem is differentiated external to the cambial initials. Outside the protoxylem points parenchymatous cells are differentiated by the cambium, and in this way the size of the entire stele is increased.

The endodermis and pericycle retain their identity as continuous bands of cells, but the cortex is composed of 15 to 17 concentric layers of cells. These cells decrease in radial diameter toward the epidermis. At the same level, lysigenous canals may occur in the outer layers of the cortical tissue.

Approximately 4 cm. above the level where transition first begins, the separation of each bundle into two units has been completed. In each unit the protoxylem is still at right angles to the metaxylem. Thick walled pericyclic cells abut on the endodermis, except over the protoxylem points where the pericycle remains parenchymatous (fig. 6). The endodermis appears as a broken band, retaining its identity only over the transition bundles. The cambium remains active and lays down xylem on the inside and phloem on the outside, while over the protoxylem points the secondary tissue remains parenchymatous.

Gradually the protoxylem points of each of the halves of the transition bundles mature opposite each other in line with the row of metaxylem cells (fig. 6). This condition is first noted in two bundles on opposite sides of the axis. In these bundles the protoxylem points are separated by four or five parenchymatous cells. In the bundles alternating with these, the points are more or less at right angles to the metaxylem.

Continuing up the axis, cambial activity decreases and the phloem groups are broken up into smaller units by the maturation of cells as parenchyma (fig. 7). The rays of parenchymatous cells between

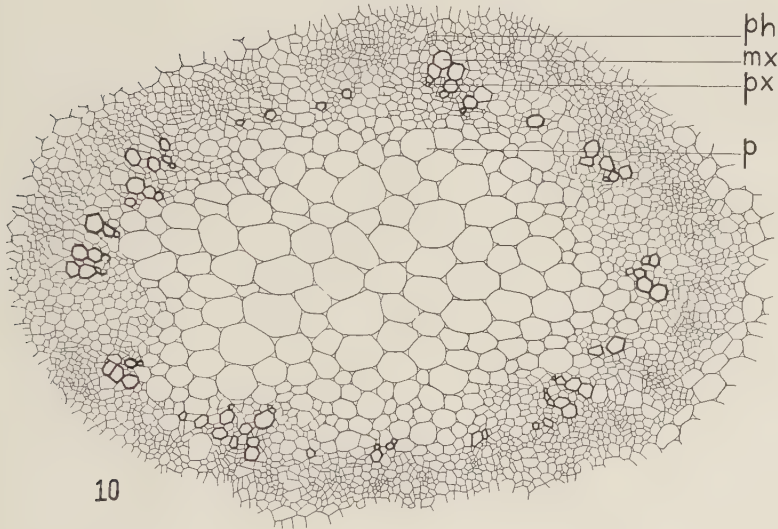
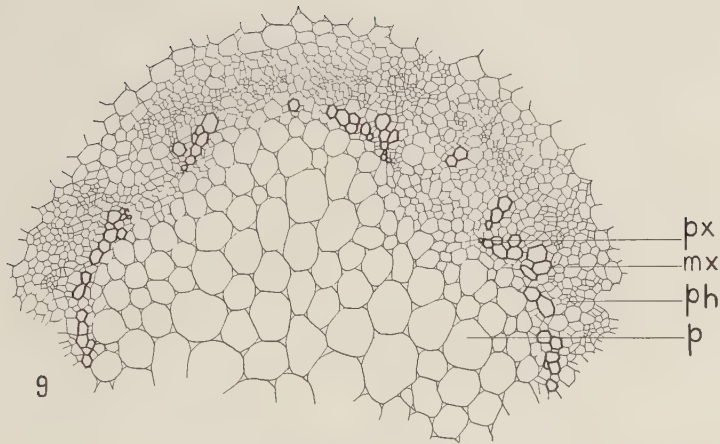
the protoxylem points in the first two bundles to mature increase in size (fig. 8). The pith as a whole remains the same size, but the cells internal to the protoxylem are much smaller in their radial diameters. The cambium at this level is just being differentiated.

The next change is a progressive maturation of the protoxylem inward and a differentiation of the metaxylem outward. Thus by a gradual centripetal differentiation of the protoxylem and a centrifugal differentiation of the metaxylem the endarch condition is reached (fig. 9). This condition occurs first in the opposite bundles. Fewer metaxylem elements mature in each bundle, indicating the more meristematic nature of this region. The parenchymatous rays separating the halves of two bundles become progressively wider, and metaxylem cells appear in the rays. The metaxylem appears progressively, with first one, then two, and finally three cells, each being separated from the other by parenchyma (fig. 9). The rays between the units of the alternate transition bundles remain two or three cells wide. There are no thick walled cells in the phloem at this level, but the sieve tubes and companion cells lie external to the four pairs of transition bundles.

Eventually the endarch condition is reached in all bundles. The rays between the units of the two bundles opposite each other are wide, with two or three endarch bundles in each ray. Alternating with these are the transition bundles in which the halves of each are separated by narrow rays containing no metaxylem elements.

Approximately 8 cm. (in the plants studied) from the soil level, the rays between the units of the two transition bundles that matured first are widened to such an extent that one unit of each bundle is on the opposite side of the axis. Thus four units of the original four transition bundles are on each side of the axis. Each of these groups consists of one original transition bundle, in which the two units are separated by narrow rays, and one unit of each bundle in which the halves are separated by wide rays.

Alternating with the two groups of four bundles are the two or three endarch bundles that differentiated in the wide rays (fig. 10). Each of these bundles consists of a single xylem element and phloem cells. The meristematic character of this level is apparent in the



FIGS. 9, 10.—Fig. 9, two pairs of transition bundles, showing metaxylem element in the wide ray between one of the pairs of bundles. Fig. 10, transverse section of hypocotyl slightly below cotyledonary plate, showing eight endarch bundles. Two pairs of bundles are separated by wide rays, with two or three metaxylem elements in each ray. The other two pairs of bundles are separated by narrow rays.

relatively few metaxylem elements in each bundle and in the undifferentiated character of the phloem region.

At the level of the cotyledonary plate, the four bundles on one side of the axis diverge into one cotyledon. The other four bundles become the vascular traces of the second cotyledon. The remainder of the axis consists of meristematic cells. An examination of the cotyledonary plate of older plants seems to indicate that the endarch bundles, differentiated in the wide rays, become the leaf traces of the axis above the divergence of the cotyledons. The connections of these bundles remain to be determined.

Summary

1. The transition from root to stem in *Gossypium hirsutum* L. is completed in the upper portion of the hypocotyl.

2. The first indication of transition from the tetrarch, exarch, protostelic primary root occurs where the metaxylem differentiates in a ring, surrounding a large pith of parenchymatous cells.

3. At a slightly higher level, parenchyma is differentiated between the metaxylem elements and four triangular shaped groups of protoxylem-metaxylem elements are formed. These are typical transition bundles.

4. Continuing up the axis, the protoxylem elements of each bundle differentiate as two rows of spiral cells, which are formed at right angles to the metaxylem. Eventually these rows are separated by parenchyma. Each transition bundle now consists of two units. At this level a cambium has differentiated secondary xylem and phloem.

5. At a higher level the protoxylem points of two bundles on opposite sides of the axis mature in line with the row of metaxylem elements. Alternating with these bundles are two transition bundles in each of which the protoxylem points are separated by parenchyma, but are at right angles to the metaxylem. Cambial activity has decreased.

6. Farther up the axis there is centripetal differentiation of the protoxylem and centrifugal differentiation of the metaxylem. Ultimately the endarch condition is reached. The rays between the halves of the two bundles that matured first are wide and from one to three metaxylem elements appear in these rays. In the alternate

bundles the rays are narrow with no metaxylem elements. The more meristematic condition of this level is indicated by the relatively few metaxylem elements in each bundle and in the undifferentiated character of the phloem.

7. At the level of the cotyledonary plate, one-half unit of each original transition bundle that matured first, and the two units of the one bundle, in which the rays are narrow, are on one side of the axis. These diverge into one cotyledon. The other bundles become the vascular traces of the second cotyledon.

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